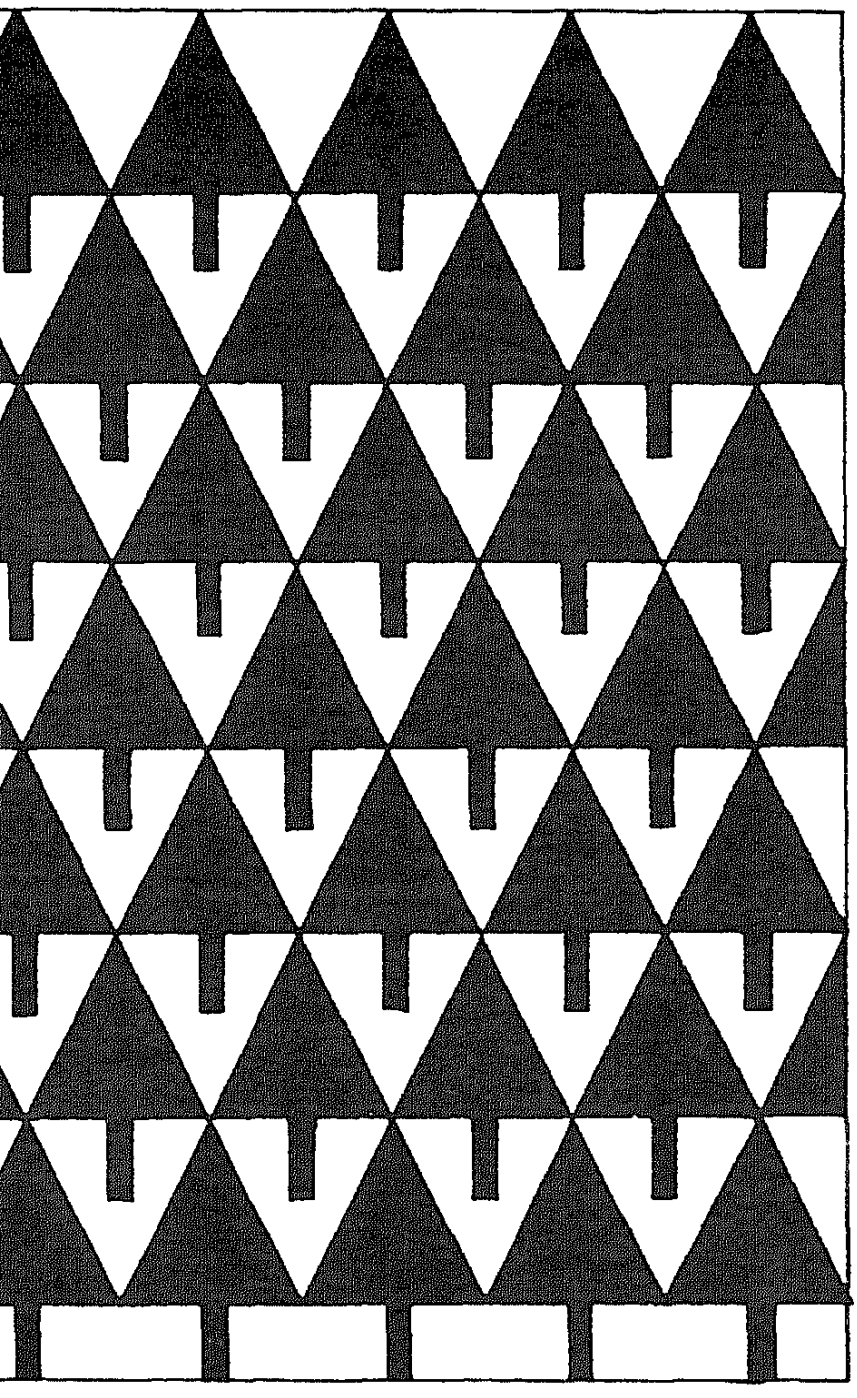
GHT GROWTH CURVES
R MANAGED,
EN-AGED STANDS OF DOUGLAS-FIR
AST OF THE CASCADES
OREGON AND WASHINGTON



P. H. COCH

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ence Abstract

an, P. H.
9. Site index and height growth curves for managed, eve
tands of Douglas-fir east of the Cascades in Oregon and
ashington. USDA For. Serv. Res. Pap. PNW-251, 16 p., il
acific Northwest Forest and Range Experiment Station, Po
regon.

Height growth and site index curves and equations for ma
aged stands of Douglas-fir (*Pseudotsuga menziezii* (Mirb.
o) east of the Cascade Range in Oregon and Washington ar
nted. Data were collected in stands where height growth
ently has not been suppressed by high density or top dam

RDS: Increment (height), site index, stem analysis, eve
stands, Douglas-fir, *Pseudotsuga menziesii*, Oregon
(eastern), Washington (eastern).

ARCH SUMMARY

arch Paper PNW-251

eight growth and site index
es and equations for managed,
aged stands of Douglas-fir
dotsuga menziesii (Mirb.)
o) east of the Cascade Range
regon and Washington were
ed from stem analysis data
22 sample plots in Oregon
0 sample plots in Washington.

known site index. Site
curves give estimates o
index of managed stands
only present breast hei
and present total heigh
available.

The appropriate curv
vide valid estimates of
index and potential hei

factors. They do not
ent the average of existing
[1] The height growth
are most appropriate for
constructing yield tables
aaged, even-aged stands of
s-fir or mixed conifers
Douglas-fir is a significant
ent.

se results stem from a
ndertaken as part of the

panded Research and Develop
Program. The purpose of th
study was to determine pote
production of stands suscep
to attack by tussock moth.

Curves are based on meas
ments of the tallest tree f
breast high age in a 1/5-ac
plot.

---

mmerfield, Edward R. Site
d height growth of Douglas-
ponderosa pine in eastern
on. Washington State Depart-
Natural Resources Report 38
aration for publication).

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APPLICATION. 8

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Height Growth Curve Construction 12

gton is in mixed conifer
s.[2] Douglas-fir (*Pseudot-
enziesii* (Mirb.) Franco) is
ary component of many of
forests occurring either in
tands or mixed primarily
hite fir (*Abies concolor*
& Glend.) Lindl.), grand
bies grandis (Dougl.)
), western larch (*Larix
ntalis* Nutt.), or ponderosa
Pinus ponderosa Laws.).
te index and height growth
presented here are for
s-fir in pure or mixed,
ged, managed stands where
vely low density, lack of
mage, and absence of vege-
competition early in the
f the stand permit full
development.

anaged stand is being
lated toward some goal,
y a "target" average diam-
nd height within a set time
To attain these goals,
nager will often use some
ation of precommercial and
cial thinnings and perhaps
suppression of competing
tion.

stands exist that have been
such management throughout
tion. Therefore, I delib-
y chose stands for sampling
pproximated densities be-
desirable in managed stands,
rely the average of existing
. Height growth from 4.5
pward was apparently never
d by stand density, vege-
competition, or top damage
se stands.[3]

are used in construction
tables for describing top
as a function of age and
index. Site index curves
used to determine an inde
potential production from
height and age (Curtis et
1974).

Methods

Data Collection

Data came from thirty-
1/5-acre circular plots
with these characteristic

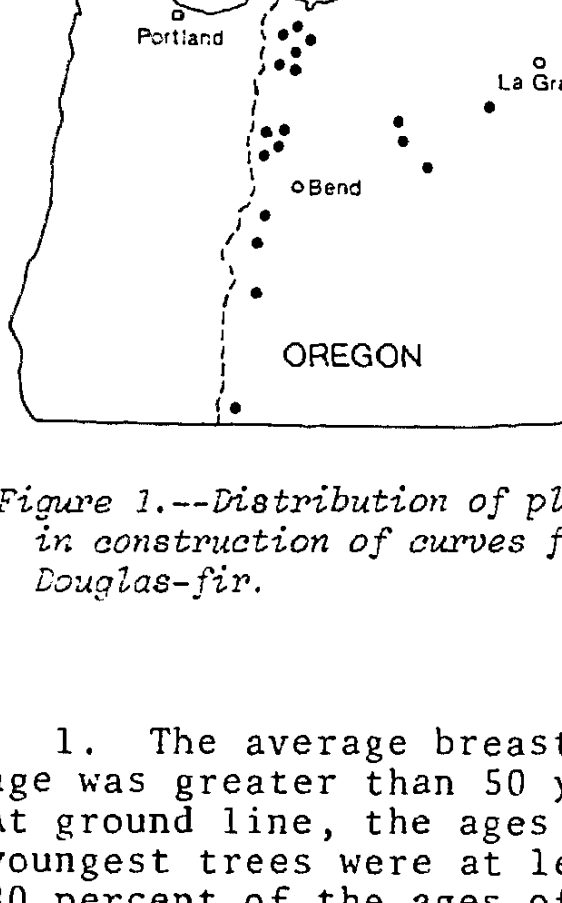

*Figure 1.--Distribution of pl
in construction of curves f
Douglas-fir.*

1. The average breast
age was greater than 50 y
At ground line, the ages
youngest trees were at le
80 percent of the ages of

The crown canopy was
d or nearly closed at the
of sampling. Stumps were
t; and mortality, if evident,
ue to suppression and was
than 5 percent of the plot
e. Volume growth patterns
he plot determined from
analysis of at least 12
e trees across the range of
ter classes indicated that
ighest periodic annual
e increment had occurred
n the last 5 to 15 years.
factors indicate that there
o severe competition between
in the past.

The dominant trees on the
did not contain a group of
w annual rings, which would
ate stress in the past.

Trees were not infected
disease, and no visible
of insect defoliation were
nt.

Dominant trees did not
it crook in the bole, and
nodal lengths did not in-
e past top damage. Some
were rejected after sampling
se abrupt breaks in the
t growth curves suggested
antial top damage 30 or
ears earlier, even though
damage was not apparent at
ime of selection.

Clumps of trees were not
ed. The plots were in
eneous stands, and each
had a buffer strip equivalent
dth to tree height.

ameter at breast height
n.) was measured for each
on each plot, and 12 to 15
of each species on each

for construction of the s
and height growth curves
in the volume determinati
Past volume and basal are
for nonsample trees on th
were predicted from their
areas. Deliberately usin
tallest tree in forming t
predictive equations woul
produced a biased overest
of volume growth.

The three to five talle
Douglas-fir trees at the
sampling were sectioned a
1-foot stump, at 4.5 feet
10 feet, and then at 10-f
intervals up the stem aft
total height was measured
tions at ground line were
taken from at least two o
largest diameter trees, t
the smallest diameter tre
one tree with close to th
diameter. Rings were cou
for all sections and reco
for the appropriate height

Curve Construction

An age of 50 years at b
height (4.5 feet) was chos
the index age. For each p
heights of the three to fi
tallest trees were plotted
function of bh age[4] for ea
on a single sheet of graph
The bh age for each tree w
as the independent variabl
the initial plotting rathe
average bh age because hei
growth from 0 to 4.5 feet
to be greatly influenced b
petition immediately adjac
a seedling and perhaps by
animal damage. Thus, it i
possible for dominant tree

differ as much as 10 years
feet. Use of an average
for plotting heights
s in an underestimate of
ight growth potential of
te under management. Shifts
tree of maximum height for
age among the sample trees
ed on 50 percent of the
Freehand curves were
for each tree and the
t points at each decadal
nterval were used in sub-
nt construction of curves.
index for each plot was
ed as the tallest height
age 50. This procedure
les that of Dahms (1963),
that Dahms used an average
r the plot as the independ-
ariable in plotting the
of height growth for the
t trees.

m this point, the method-
outlined by Barrett (1978)
ed; it includes the recent
vements in curve construction
s suggested by Curtis et al.
and Dahms (1975). A brief
e is presented in the
dix.

r the 10 sample plots in
ngton, site indexes ranged
5 to 105.4. The 22 sample
in Oregon had site indexes
g from 52.7 to 106.4. The
ge site index was 84.47:

Number of plots	Site Index
4	50-59
4	60-69
3	70-79
3	80-89
13	90-99
5	100-110

construction. Some under
of curve construction lea
appreciation of how they
be used so the appendix
mended reading even for
casional user.

Estimating Site Inde

Site index curves are
indicate the potential pr
of land. The curves here
estimated height of the
tree when the breast high
that tree is 50 years.
the same plot qualificati
in this study are applica
selecting plots for measu
site index. The followi
and procedures are recomm
for estimating the site
a managed stand.

1. Select suitable pl
the following characteri

(a) Even-aged at the
line (practically, th
no older remanents fr
stands and the presen
is one storied).

(b) No visible signs
disease or insect att
reduce height growth.

(c) No narrow ring g
indicate suppression.

(d) Consistent inter
lengths on taller tre

(e) No remnant under
vegetation or suppres
mortality to indicate
petition early in the
of a stand.

2. Establish boundar

etermine a site index value for
ach tree by one or more of the
llowing alternatives.

(a) Use figure 2 for rough field estimates.

(b) Obtain a more precise estimate by using the appropriate a and b values in table 1 to solve the equation,

cedure in a calcula
appropriate equatio
appendix can be use

6. Record as the s
value for the plot, th
of the three to five v
determined.

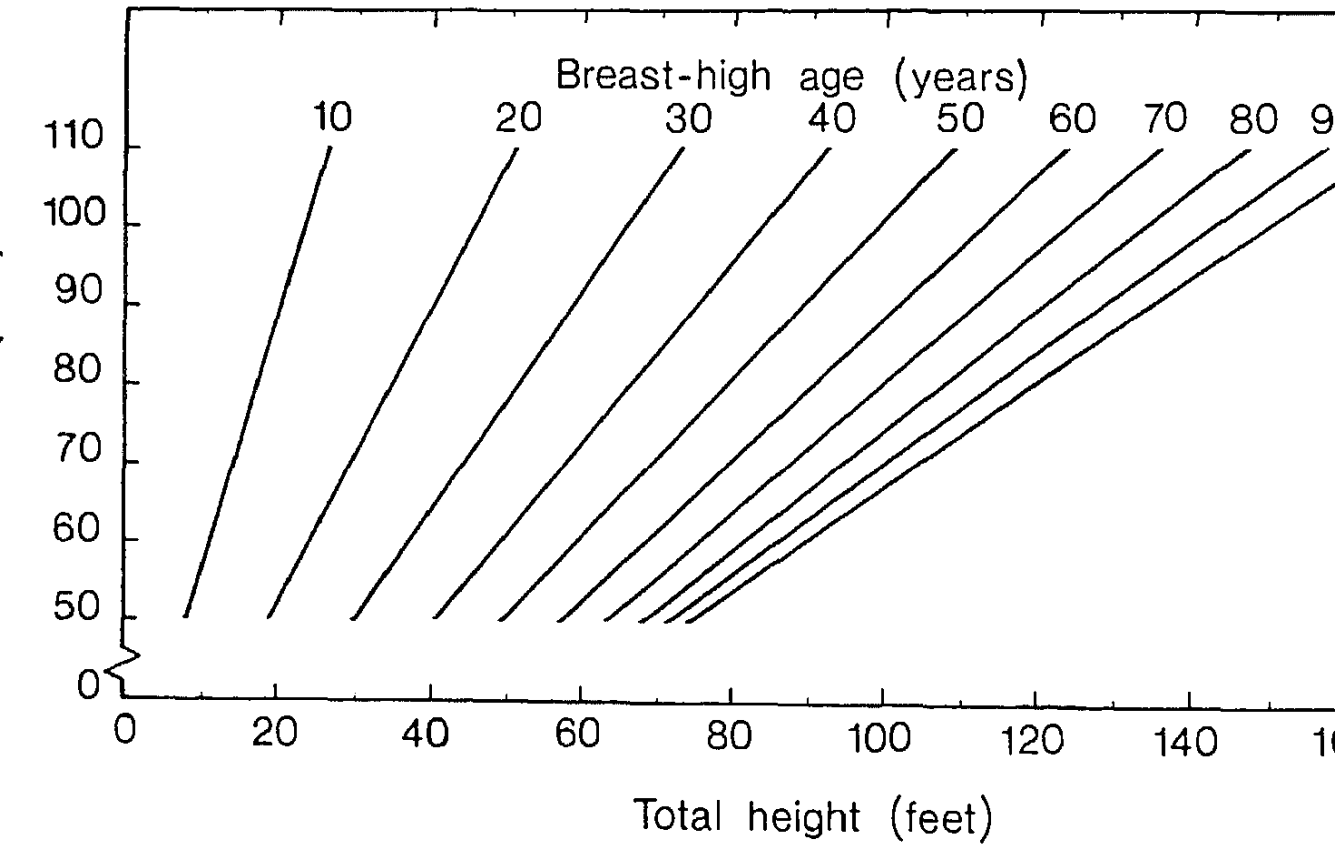

Table 1--Values for a and b by years for the family of regressions[1/] for estimating site index for Douglas-fir east of the Cascades in the Pacific Northwest

Breast-high age	Years between decades																	
	0		1		2		3		4		5		6		7		8	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																		
10	32.217	3.235	30.319	2.996	28.679	2.778	27.069	2.602	25.560	2.451	24.113	2.319	22.751	2.204	21.457	2.103	20.238	2.01
20	17.940	1.858	16.875	1.792	15.585	1.731	14.886	1.676	13.958	1.625	13.069	1.579	12.219	1.535	11.406	1.495	10.637	1.45
30	9.168	1.390	8.484	1.359	7.830	1.331	7.204	1.304	6.605	1.278	6.032	1.254	5.483	1.231	4.959	1.209	4.458	1.18
40	3.522	1.150	3.085	1.132	2.760	1.114	2.274	1.098	1.896	1.082	1.537	1.067	1.196	1.053	.877	1.039	.565	1.02
50	0	1	-.260	.988	-.505	.976	-.735	.965	-.951	.954	-1.153	.944	-1.342	.934	-1.518	.924	-1.681	.91
60	-1.971	.896	-2.098	.887	-2.214	.879	-2.319	.870	-2.413	.862	-2.496	.854	-2.569	.847	-2.632	.839	-2.685	.83
70	-2.764	.818	-2.789	.811	-2.806	.804	-2.814	.798	-2.814	.791	-2.805	.785	-2.789	.779	-2.764	.773	-2.732	.76
80	-2.646	.756	-2.593	.750	-2.532	.745	-2.465	.740	-2.391	.734	-2.311	.729	-2.224	.724	-2.132	.719	-2.034	.71
90	-1.818	.709	-1.703	.700	-1.582	.695	-1.455	.691	-1.324	.687	-1.187	.682	-1.046	-.961	-.900	.674	-.747	.66
100	-.434	.661																

[1/]To estimate site index, measure height of the 3 tallest trees per 1/5-acre plot. Determine breast-high age for each of these trees. appropriate a and b values above. Substitute values in the equation, Site index - 4.5 feet = a + b (height - 4.5 feet). For example, for a 53 years old at breast height and 60 feet in total height, solve the equation, SI - 4.5 = -0.735 + 0.965 (60 - 4.5), for a site index of 57. Determine the site index for each of the 3 trees. The highest site index determined is the site index for the 1/5-acre plot.

nating the Course of
ht Growth for Stands
Given Site Quality

ight growth curves define
erage pattern of height
opment for the tallest trees
ands of a given site quality.
are appropriately used for
ruction of yield tables but
t provide optimum estimates
te index from measured
t and age in an existing
(Curtis et al. 1974).

Three alternatives exi
estimating the anticipate
of the tallest trees of a
on land of known site ind

1. Rough field estima
through use of figure 3.

2. A more precise est
using a_1 and b_1 values ir
in the equation,

Height - 4.5 feet =
$a_1 + b_1$ (site index - 4.

3. An estimating proc
programed in a calculator
the equation shown in the

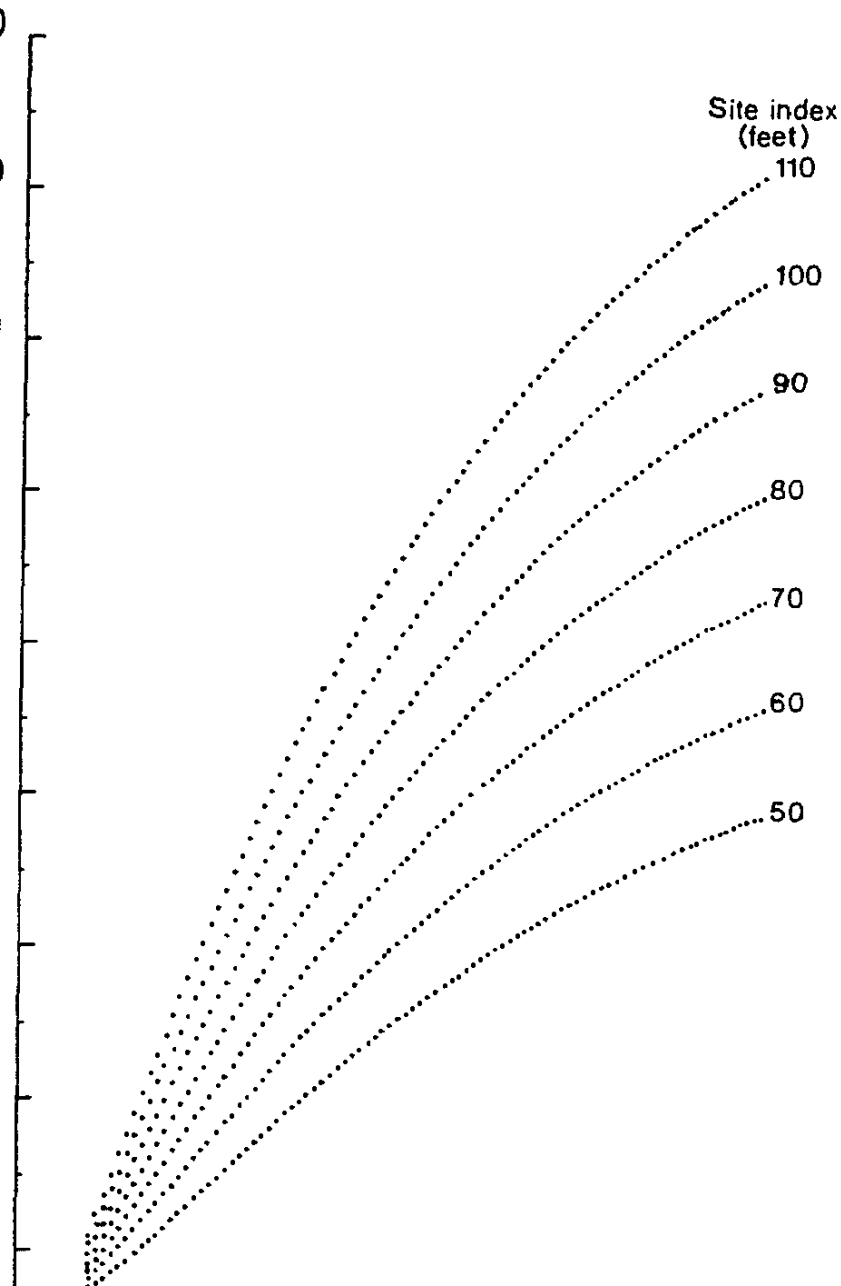

*Figure 3.--Height growt
for the tallest trees
even-aged stands of D
east of the Cascades
Pacific Northwest.*

Table 2--Values for a and b by years for the family of regressions[1/] for estimating height of the tallest trees in a newly established stand of Douglas-fir east of the Cascades where site index and age are known

Years between decades																	
1		2		3		4		5		6		7		8		9	
b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a
0.115	4.407	0.149	3.924	0.182	3.216	0.214	2.575	0.245	1.997	0.276	1.475	0.306	1.006	0.335	0.586	0.364	0.[illegible]	0.[illegible]
.419	-.422	.446	-.683	.472	-.911	.497	-1.108	.522	-1.127	.546	-1.418	.570	-1.534	.593	-1.627	.615	-1.[illegible]	.637
.659	-1.781	.680	-1.795	.700	-1.192	.720	-1.773	.740	-1.740	.759	-1.692	.778	-1.632	.796	-1.560	.814	-1.[illegible]	.[illegible]
.849	-1.279	.866	-1.166	.882	-1.045	.898	-.915	.913	-.778	.929	-.634	.944	-.484	.958	-.328	.972	-1.166	.9[illegible]
1.000	.172	1.013	.348	1.026	.578	1.039	.711	1.051	.898	1.064	1.087	1.075	1.279	1.087	1.474	1.098	1.670	1.110
1.120	2.069	1.131	2.270	1.141	2.473	1.151	2.676	1.161	2.881	1.171	3.085	1.181	3.290	1.190	3.496	1.199	3.701	1.[illegible]
1.216	4.110	1.225	4.315	1.233	4.518	1.241	4.721	1.249	4.923	1.257	5.124	1.264	5.324	1.272	5.525	1.279	5.720	1.[illegible]
1.293	6.110	1.300	6.303	1.306	6.494	1.313	6.684	1.319	6.871	1.325	7.057	1.331	7.241	1.337	7.422	1.343	7.[illegible]	1.349
1.354	7.954	1.359	8.126	1.365	8.297	1.370	8.465	1.375	8.630	1.380	8.793	1.385	8.954	1.389	9.112	1.394	9.267	1.[illegible]
1.403																		

at a future date of the tallest portion of a young stand may be estimated on land of known site index by selecting a and b values for the east-high age. Substitute a_1 and b_1 values in the equation, Height - 4.5 feet = a_1 + b_1 (site index - 4.5 feet), for the particular e wanted. For example, for the height of the tallest tree in the stand at breast-high age 85 on land with a known site index of 100, tion, HT - 4.5 = 6.871 + 1.325 (100 - 4.5), for a total height of 137.9 feet.

...ication

this study, site index is ...ber representing the height ...e tallest tree for its ...t-high age of 50 years on ...-acre plot. Since site has ...found to be closely cor...ed with volume (Spurr 1952), ...index (as discussed here) ...later be used in a yield ... to categorize volume pro...vity potentials of managed ...s of Douglas-fir east of ...ascades. Height objectively ...cts site where undamaged ...s are not overstocked. ...s managed for maximum pro...on of usable wood, in con... to natural stands, probably ...not be overstocked to the ... of substantially reducing ...t growth. Therefore, use ...ese curves should be re...ted to even-aged stands ... height growth competition ...en trees has been held to ...imum.

...pical examples of when the ...s should not be used are:

... Precommercially thinned ...s showing a tight core of ...

... Commercially thinned ...s with numerous stumps in...ng a high initial density.

... Plantations with large ...rs of trees, thinned long ... severe competition between ... occurred.

... Stands that have been ...ted to Douglas-fir tussock ... spruce budworm, or other ... attacks that resulted in ...f top growth.

models. Stand projectio... assign appropriate lesse... to other than the talles... in the stand. This prob... height assignment is cur... being investigated.

A partial judgment of ... reliability of the curves ... be made by the r^2 values ... the standard errors of th... estimates shown in the ap... Equation fit can be judge... figures 8 and 9 in the ap...

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Snedecor, George W., and Willia...

For both site index and height growth curves, a curve of
ght for the samples as a function of age at 4.5 feet is c
s height curve is then adjusted to the desired site index
linear relationship existing between height and site ind
, with appropriate estimates of slope and intercept. The
different because slope and intercept values of the equa

$$SI - 4.5 \text{ feet} = a + b\,(HT - 4.5 \text{ feet}) \text{ and}$$

$$HT - 4.5 \text{ feet} = a_1 + b_1\,(SI - 4.5 \text{ feet})$$

different for all ages except the index age (50 years fo
ves).

INDEX CURVE CONSTRUCTION

1. For the site index curves, the tallest heights (HT) a
ade were read from the freehand curves and related to the
ex (SI) for each plot by the equation,

$$SI - 4.5 \text{ feet} = a + b\,(HT - 4.5 \text{ feet}).$$

following estimates were obtained:

Breast-high age (years)	a	b	r^2	Standard error of the estimate	Numb observ
10	32.2881	3.2310	0.3803	13.09	3
20	17.2388	1.8723	.7681	8.01	3
30	9.3532	1.3814	.9096	5.00	3
40	4.3867	1.1326	.9713	2.82	3
50	0	1	1	0	3
60	-1.7380	.8978	.9831	2.17	3
70	-1.1413	.8042	.9519	3.73	2
80	1.6845	.7048	.9498	3.98	1
90	-3.0283	.7101	.9489	3.96	1
100	-2.6900	.6767	.9399	4.03	1

The 10 sample plots with a bh age of 90 or more years hav
exes of 54.3, 55, 65.2, 69, 69.2, 81.8, 91, 91.6, 95, and

2. The above decadal estimates of b were smoothed over a
the equation (forced though a b value of 1 at a breast-hi
years),

$$\hat{b} = 0.52032 - 0.0013194\ age + 27.2823/age;$$

re age here and in the equations to follow is breast high
ndard error[5] and R^2 values for this equation are 0.0213 a

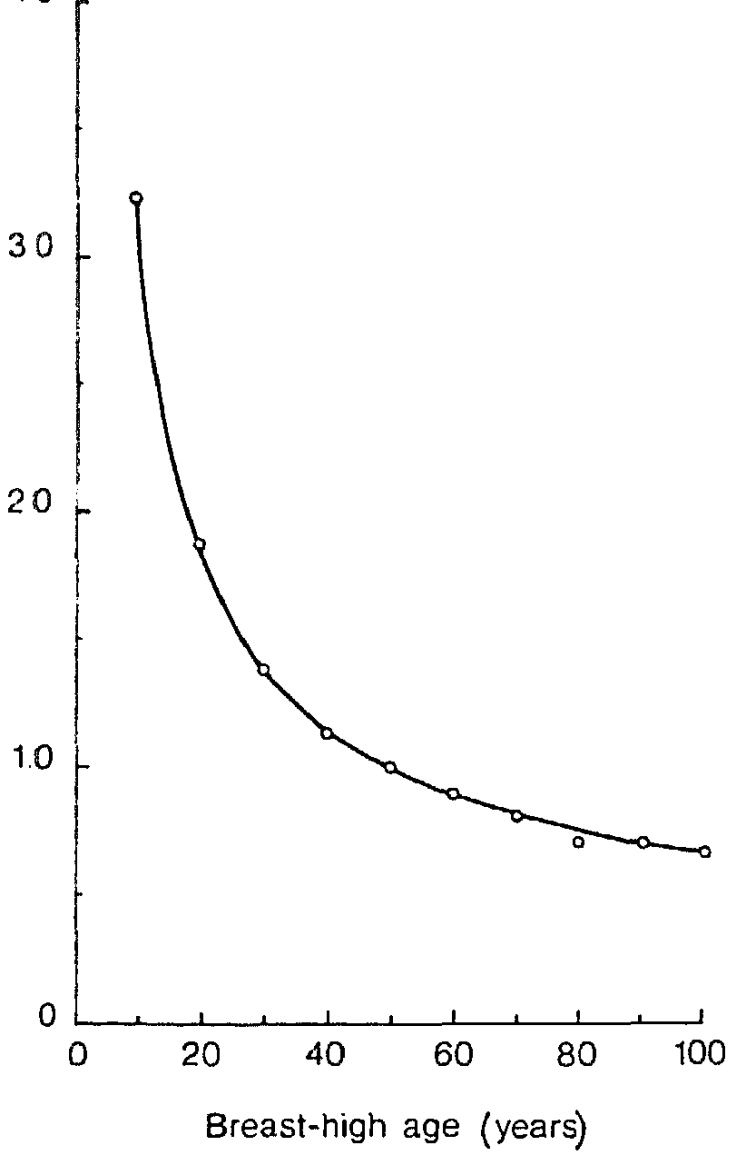

Figure 4.--b values in equat
SI - 4.5 feet = a + b (HT
as a function of age. Poi
actual b values. Solid li
curve expressed by the equ
$\hat{b}$ = 0.52032 - 0.0013194 ag
27.2823/age.

The resulting $\hat{b}$ values are those appearing in table 1.

3. The following equation (with a standard error of 0.54
R^2 of 0.9999), expressing decadal mean heights as a funct
, was conditioned to pass through mean site index (SI = 8
years (fig. 5):

$$\hat{HT} - 4.5 = e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e}$$

e $\hat{HT}$ is an estimate of $\overline{HT}$. At ages beyond 50 years, the
ame progressively smaller and mean site index was slightl
rage heights were adjusted to the mean overall site index
b_1 values of the individual regressions of

$$HT - 4.5 = a_1 + b_1 (SI - 4.5)$$

each decade in the equation,

Adjusted average height - 4.5 feet = $a_1 + b_1$ (84.47 -

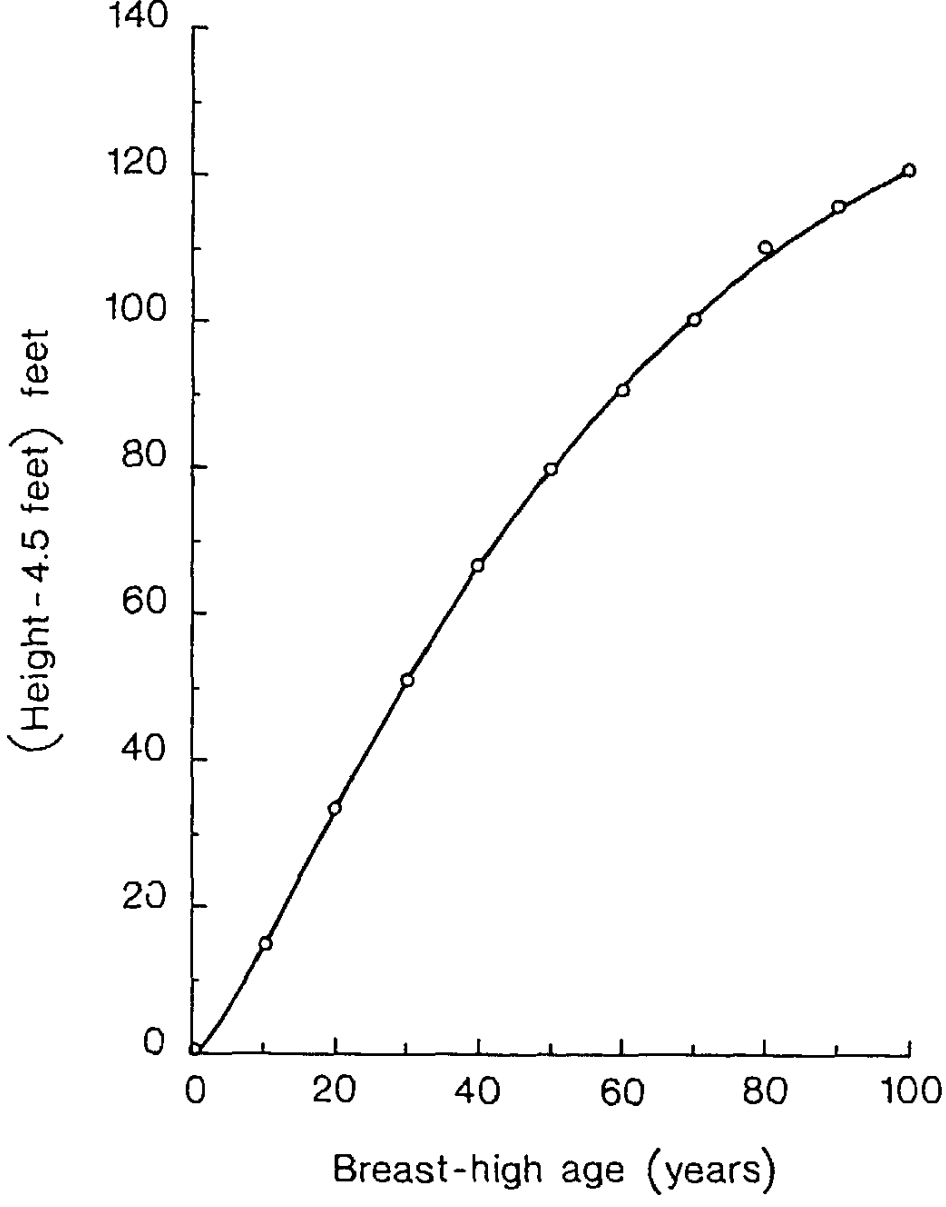

Figure 5.--Average height of sectioned trees as a function of breast-high age. Points are average heights - 4.5 feet. Solid line is curve expressed by the equation,

$$\overline{HT} - 4.5 \text{ feet} = e^{(-0.37496 + 1.36164 (\log_e age) - 0.00243434 (\log_e age)^4)}.$$

T and the smoothed slope b of regressions for each year w
d to calculate the corresponding intercept a:

$$\hat{a} = \overline{SI} - 4.5 - \hat{b} (\hat{HT} - 4.5).$$

values appear in table 1.

ubstituting expressions for a, b, and HT in the basic equ

ion,

$$HT - 4.5 = a_1 + b_1 (SI - 4.5);$$

following estimates were obtained:

Breast-high age (years)	a_1	b_1	r^2	Standard error of the estimate	Numbe observat
10	5.3429	0.1177	0.3803	2.50	32
20	.6967	.4103	.7681	3.75	32
30	-1.5405	.6584	.9096	3.45	32
40	-1.8455	.8576	.9713	2.45	32
50	0	1	1	0	32
60	3.4273	1.0950	.9831	2.40	30
70	6.1089	1.1837	.9519	4.53	28
80	2.8416	1.3477	.9498	5.51	18
90	9.5137	1.3358	.9486	5.43	10
100	10.4112	1.3889	.9399	6.13	10

. The above decadal estimates of b_1 were smoothed over ag
. 6) by the equation,

$$\hat{b}_1 = -0.2828 + 1.87947(1 - e^{-0.022399\ age})^{0.966998};$$

resulting $\hat{b}_1$ values are those appearing in table 2. The s
r and R^2 values are 0.0278 and 0.9969 for this equation whi
ed through a b_1 value of 1 at age 50 years. These standar
R^2 values are not measures of variation within the sampled
on; they are given merely to show how well the fitted equa
ribed the actual slope values for each decadal age.

. The same expression for decadal height used in determi
x was used again with the mean site index (SI = 84.47) in
rrangement of the basic equation,

$$\hat{a}_1 = \hat{HT} - 4.5 - \hat{b}_1 (\bar{SI} - 4.5)$$

roduce the a_1 values shown in table 2.

. Appropriate rearrangement and substitution for a_1, b_1,
he basic equation give the final equation used to estimat
function of age and site index as shown in figure 2:

$$T = 4.5 + e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e ag}$$

$$79.97\ (-0.2828 + 1.87947\ (1 - e^{-0.022399\ age})^{0.966998}$$

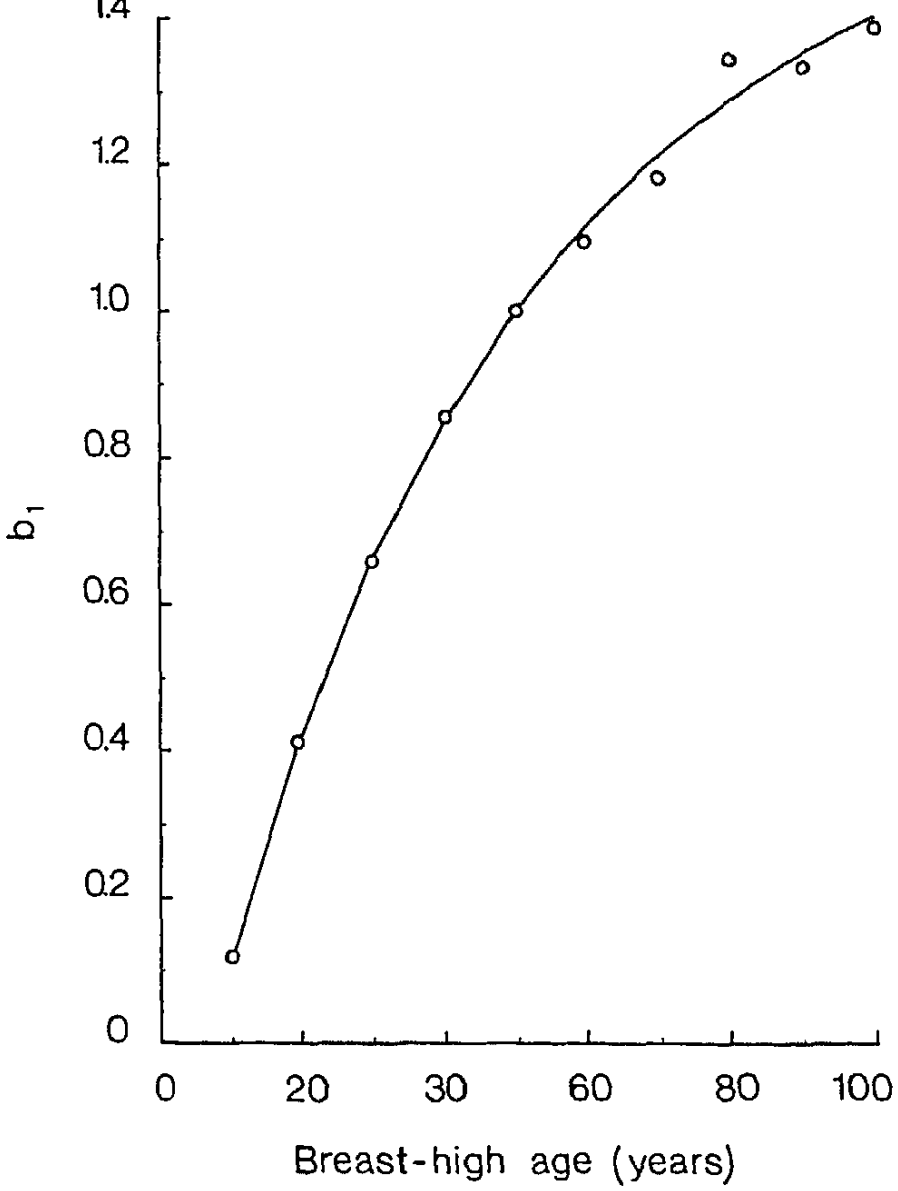

Figure 6.--b_1 values in the equation HT - 4.5 feet = a_1 + b_1 (SI - 4.5 feet) as a function of age. Points are actual b_1 values. Solid line is expressed by the equation,

$$\hat{b}_1 = -0.2828 + 1.87947\ (1 - e^{-0.022399\ age})^{0.966998}.$$

aphic comparison between site index and the height growth is shown in figure 7.

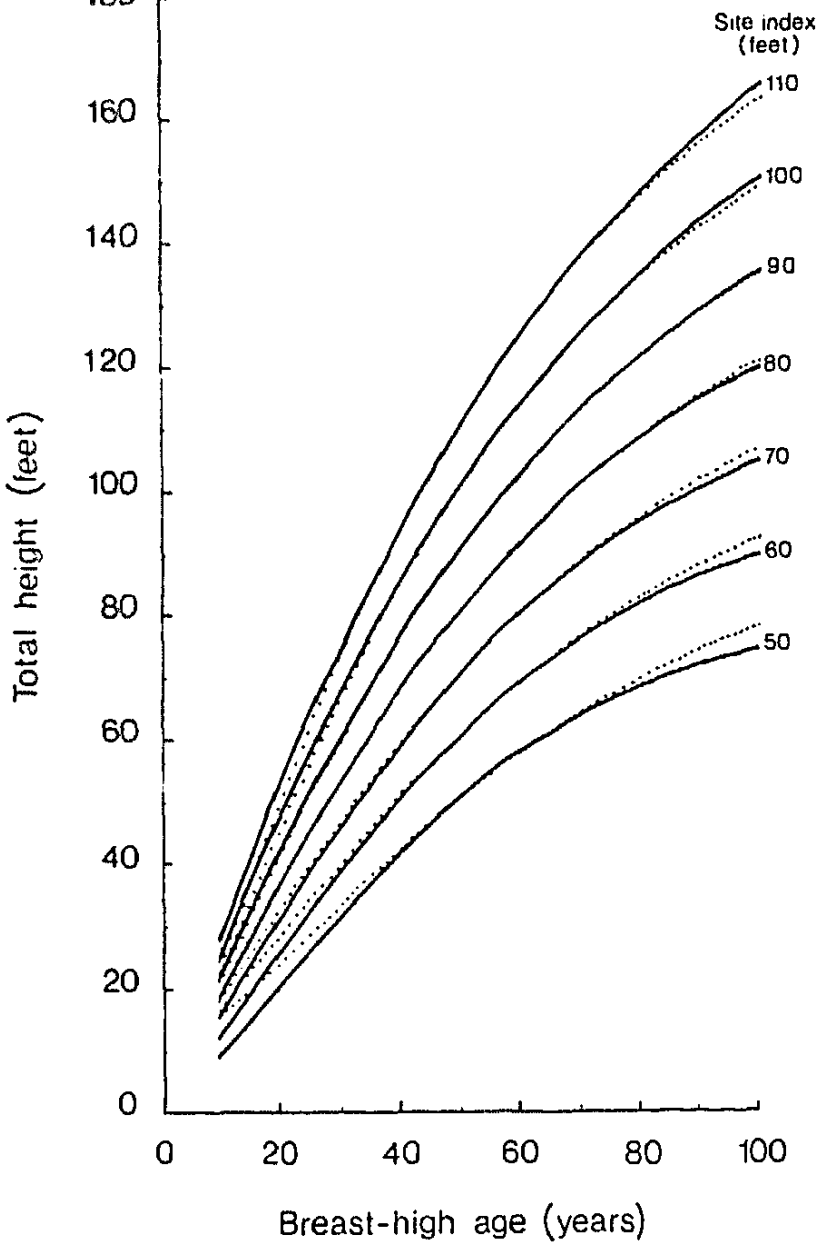

Figure 7.--Site index (solid lines) and height growth curves (dashed lines) for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest.

final estimating equations for both site and height fit t
data regression points well (figs. 8 and 9).

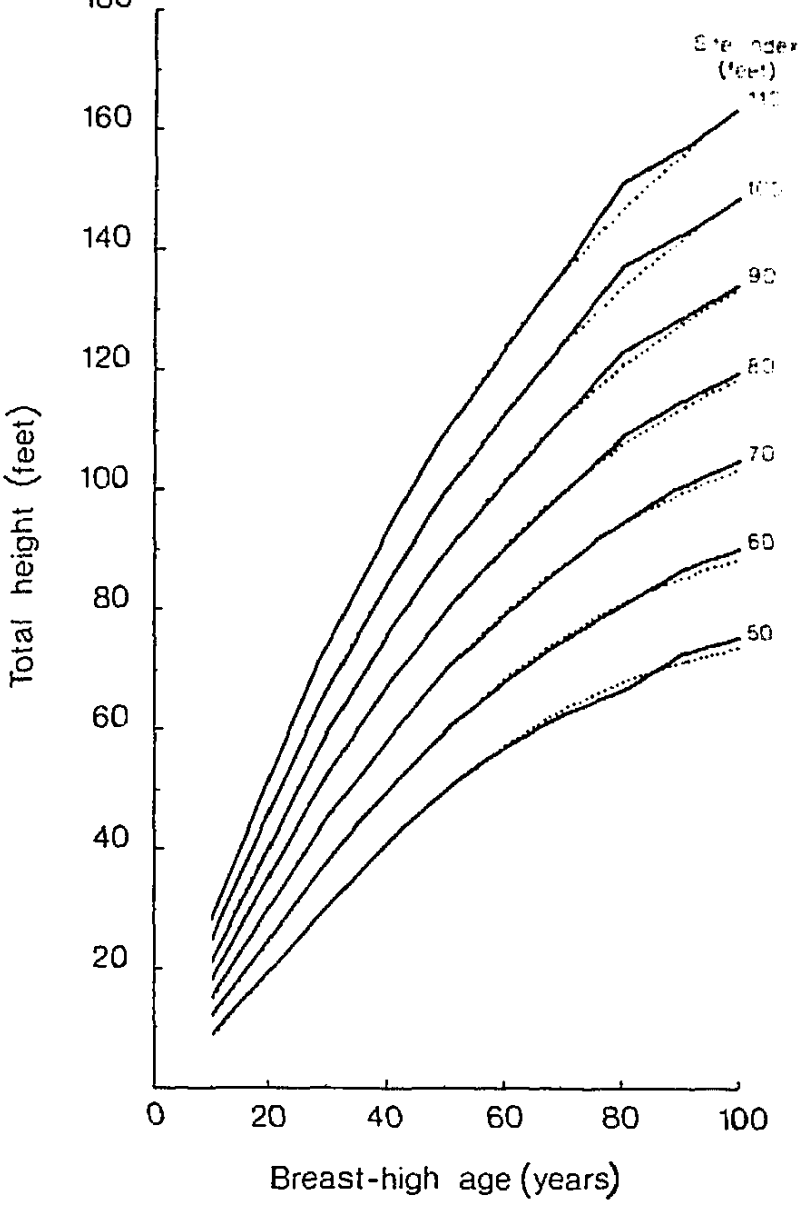

Figure 8.--Site index curves for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest. Solid lines connect decadal points derived from the unsmoothed basic data regressions of the equation, $SI - 4.5 = a + b\ (HT - 4.5)$. Dashed lines represent smooth curves from the following rearrangement of the estimating equation,

$$HT = 4.5 + ((SI - 84.47) + (0.52032 - 0.0013194\ age + 27.2823/age))\ (e^{(-0.37496 + 1.36164(\log_e age) - 0.00243434(\log_e age)^4)})/(0.52032$$

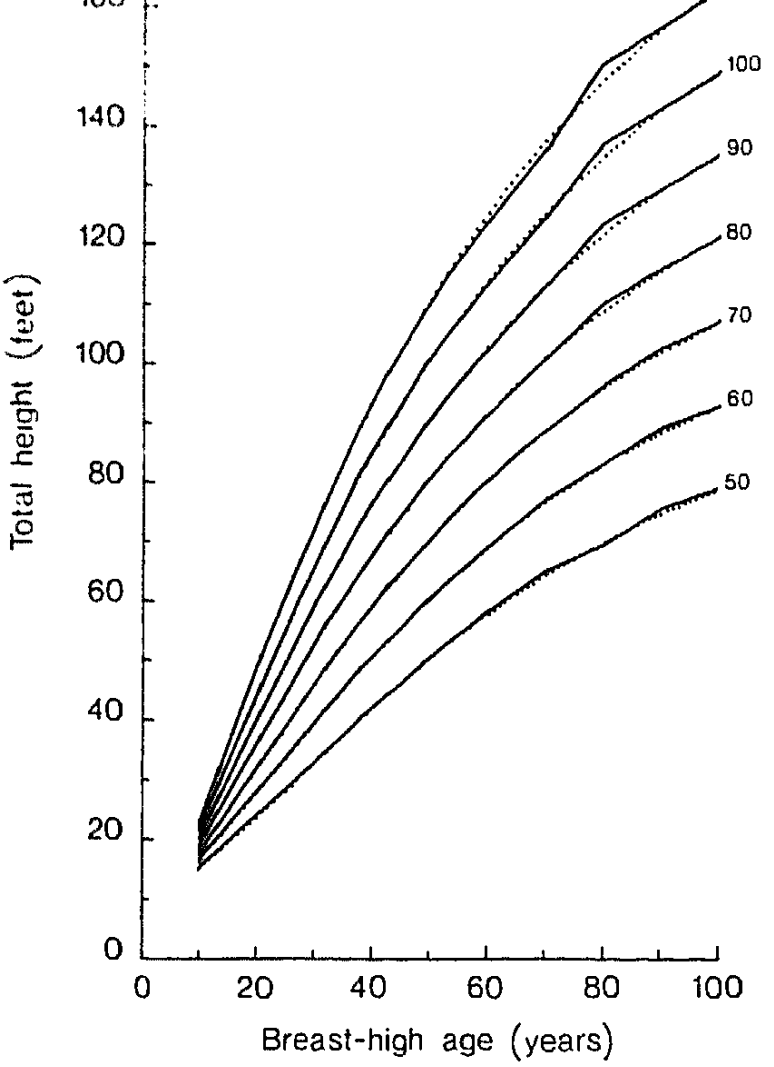

Figure 9.--Height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in the Pacific Northwest. Solid lines connect decadal points derived from unsmoothed basic data regression of the equation,

$$HT - 4.5 = a_1 + b_1 (SI - 4.5).$$

Dashed lines represent smooth curves from the estimating equations.

index and height growth curves for managed, even-
ds of Douglas-fir east of the Cascades in Oregon
ngton. USDA For. Serv. Res. Pap. PNW-251, 16 p.,
acific Northwest Forest and Range Experiment
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1979. Site index and height growth curves for
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KEYWORDS: Increment (height), site index, stem a
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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

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